

TITLE OF THE INVENTION

WIRING STRUCTURE ON SEMICONDUCTOR SUBSTRATE AND METHOD  
OF FABRICATING THE SAME

CROSS-REFERENCE TO RELATED APPLICATIONS

5        This application is based upon and claims the benefit of priority from the prior Japanese Patent Applications No. 2002-324973, filed November 8, 2002; No. 2003-147447, filed May 26, 2003; No. 2003-324204, filed September 17, 2003, the entire contents of all of  
10      which are incorporated herein by reference.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a wiring structure on a semiconductor substrate and, more particularly, to a wiring structure capable of preventing ion migration between interconnections formed at fine pitches, and a method of fabricating the same.

2. Description of the Related Art

20      A conventional semiconductor device called a CSP (chip size package) is as follows. On a semiconductor substrate having connecting pads on its upper surface, copper distribution wires are connected to the connecting pads via an insulating film interposed therebetween. A copper bump electrode is formed on a connecting pad portion of each distribution wire. An encapsulating film is formed on the insulating film and

the distribution wires such that the upper surface of the encapsulating film is leveled with the upper surfaces of the bump electrodes (e.g., USP6,600,234B2).

In the above conventional semiconductor device, as shown in FIG. 7 of USP6,600,234B2, a wiring substrate metal layer is formed on a substantially flat upper surface of an insulating film. Therefore, if water in the use environment penetrates into the encapsulating film, copper ions flowing out from the wiring substrate metal layer or bump electrodes 57 to which a positive voltage is applied move in the interface between the insulating film and encapsulating film, and precipitate in the wiring substrate metal layer 56 or bump electrodes to which a negative voltage is applied, thereby causing a short circuit by so-called ion migration.

It is, therefore, an object of the present invention to provide a semiconductor device capable of preventing easy occurrence of a short circuit caused by so-called ion migration, and a method of fabricating the same.

#### BRIEF SUMMARY OF THE INVENTION

According to an aspect of the present invention, there is provided a semiconductor device comprising a semiconductor substrate having a plurality of connecting pads on one surface, an insulating film formed on one surface of the semiconductor substrate.

The insulating film has holes each corresponding to one of the connecting pads, an upper surface, and a recess having a bottom surface depressed from the upper surface in a direction of thickness. Interconnections  
5 are formed on the upper surface of the insulating film or on the bottom surface of the recess, and connected to the connecting pads through the holes in the insulating film.

According to another aspect of the present  
10 invention, there is provided a semiconductor device fabrication method comprising preparing a semiconductor substrate having a plurality of connecting pads on one surface, forming, on one surface of the semiconductor substrate, an insulating film having holes each corresponding to one of the connecting pads, an upper surface, and a recess having a bottom surface depressed from the upper surface in a direction of thickness, and forming, on the upper surface of the insulating film or on the bottom surface of the recess, interconnections  
15 connected to the connecting pads through the holes in the insulating film.

Additional objects and advantages of the invention will be set forth in the description which follows, and in part will be obvious from the description, or may be learned by practice of the invention. The objects and  
25 advantages of the invention may be realized and obtained by means of the instrumentalities and

combinations particularly pointed out hereinafter.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWING

The accompanying drawings, which are incorporated in and constitute a part of the specification,

5 illustrate embodiments of the invention, and together with the general description given above and the detailed description of the embodiments given below, serve to explain the principles of the invention.

FIG. 1 is an enlarged sectional view of a  
10 semiconductor device according to the first embodiment  
of the present invention;

FIG. 2 is an enlarged sectional view of an initial fabrication step in the fabrication of the semiconductor device shown in FIG. 1;

15 FIG. 3 is an enlarged sectional view of a fabrication step following FIG. 2;

FIG. 4 is an enlarged sectional view of a fabrication step following FIG. 3;

20 FIG. 5 is an enlarged sectional view of a fabrication step following FIG. 4;

FIG. 6 is an enlarged sectional view of a fabrication step following FIG. 5;

FIG. 7 is an enlarged sectional view of a fabrication step following FIG. 6;

25 FIG. 8 is an enlarged sectional view of a fabrication step following FIG. 7;

FIG. 9 is an enlarged sectional view of a

fabrication step following FIG. 8;

FIG. 10 is an enlarged sectional view of a fabrication step following FIG. 9;

5 FIG. 11 is an enlarged sectional view of a fabrication step following FIG. 10;

FIG. 12 is an enlarged sectional view for explaining another formation method of a protective film;

10 FIG. 13 is an enlarged sectional view of a semiconductor device as the first modification of the first embodiment shown in FIG. 1;

FIG. 14 is an enlarged sectional view of a semiconductor device as the second modification of the first embodiment shown in FIG. 1;

15 FIG. 15 is an enlarged sectional view of a semiconductor device as the third modification of the first embodiment shown in FIG. 1;

20 FIG. 16 is an enlarged sectional view of a semiconductor device according to the second embodiment of the present invention;

FIG. 17 is an enlarged sectional view of an initial fabrication step in the fabrication of the semiconductor device shown in FIG. 16;

25 FIG. 18 is an enlarged sectional view of a fabrication step following FIG. 17;

FIG. 19 is an enlarged sectional view of a fabrication step following FIG. 18;

FIG. 20 is an enlarged sectional view of a fabrication step following FIG. 19;

FIG. 21 is an enlarged sectional view of a fabrication step following FIG. 20;

5 FIG. 22 is an enlarged sectional view of a fabrication step following FIG. 21;

FIG. 23 is an enlarged sectional view of a fabrication step following FIG. 22;

10 FIG. 24 is an enlarged sectional view of a fabrication step following FIG. 23;

FIG. 25 is an enlarged sectional view of a fabrication step following FIG. 24;

FIG. 26 is an enlarged sectional view of a fabrication step following FIG. 25;

15 FIG. 27 is an enlarged sectional view of a fabrication step following FIG. 26;

FIG. 28 is an enlarged sectional view of a fabrication step following FIG. 27;

20 FIG. 29 is an enlarged sectional view of a fabrication step following FIG. 28;

FIG. 30 is an enlarged sectional view of a fabrication step following FIG. 29;

FIG. 31 is an enlarged sectional view of a fabrication step following FIG. 30;

25 FIG. 32 is an enlarged sectional view of a fabrication step following FIG. 31;

FIG. 33 is an enlarged sectional view of a

fabrication step following FIG. 32;

FIG. 34 is an enlarged sectional view of a fabrication step following FIG. 33;

5 FIG. 35 is an enlarged sectional view of a predetermined step for explaining another fabrication method of the semiconductor device shown in FIG. 16;

FIG. 36 is an enlarged sectional view of a step following FIG. 35;

10 FIG. 37 is an enlarged sectional view of a step following FIG. 36;

FIG. 38 is an enlarged sectional view of a semiconductor device as the first modification of the second embodiment of the present invention shown in FIG. 16;

15 FIG. 39 is an enlarged sectional view of a semiconductor device as the second modification of the second embodiment of the present invention shown in FIG. 16;

20 FIG. 40 is an enlarged sectional view of a semiconductor device as the third modification of the second embodiment of the present invention shown in FIG. 16;

25 FIG. 41 is an enlarged sectional view of a semiconductor device as the fourth modification of the second embodiment of the present invention shown in FIG. 16;

FIG. 42 is an enlarged sectional view of a

semiconductor device according to the third embodiment of the present invention;

FIG. 43 is an enlarged sectional view of an initially prepared structure in the fabrication of the 5 semiconductor device shown in FIG. 42;

FIG. 44 is an enlarged sectional view of a fabrication step following FIG. 43;

FIG. 45 is an enlarged sectional view of a fabrication step following FIG. 44;

10 FIG. 46 is an enlarged sectional view of a fabrication step following FIG. 45;

FIG. 47 is an enlarged sectional view of a fabrication step following FIG. 46;

15 FIG. 48 is an enlarged sectional view of a fabrication step following FIG. 47;

FIG. 49 is an enlarged sectional view of a fabrication step following FIG. 48;

20 FIG. 50 is an enlarged sectional view of a semiconductor device as a modification of the third embodiment of the present invention shown in FIG. 42;

FIG. 51 is an enlarged sectional view of a step corresponding to FIG. 44, in the fabrication of the semiconductor device shown in FIG. 50;

25 FIG. 52 is an enlarged sectional view of a fabrication step following FIG. 51;

FIG. 53 is an enlarged sectional view of a fabrication step following FIG. 52;

FIG. 54 is an enlarged sectional view of a fabrication step following FIG. 53;

FIG. 55 is an enlarged sectional view of a fabrication step following FIG. 54; and

5 FIG. 56 is an enlarged sectional view of a fabrication step following FIG. 55.

#### DETAILED DESCRIPTION OF THE INVENTION

##### (First Embodiment)

FIG. 1 is a sectional view of a semiconductor device according to the first embodiment of the present invention. The semiconductor device includes a silicon substrate (semiconductor substrate) 1. An integrated circuit or circuits (not shown) are formed in a central portion of the upper surface of the silicon substrate 1. A plurality of connecting pads 2 made of an aluminum-based metal are formed in a peripheral portion of the upper surface so as to be electrically connected to the integrated circuit. An insulating film 3 made of silicon oxide is formed on the upper surfaces of the silicon substrate 1 and connecting pads 2 except for central portions of the connecting pads 2. The central portions of the connecting pads 2 are exposed through holes 4 formed in the insulating film 3.

A protective film (insulating film) 5 made of an organic resin such as polyimide is formed on the upper surface of the insulating film 3. Holes 6 are formed in those portions of the protective film 5, which

correspond to the holes 4 in the insulating film 3. Recesses 7 are formed in distribution wire formation regions of the upper surface of the protective film 5. The recesses 7 communicate with the holes 6.

5 A distribution wire 8 is formed from the upper surface of each connecting pad 2 exposed through the holes 4 and 6 to a predetermined portion of the upper surface of the protective film 5 in the recess 7. The distribution wire 8 is made up of a lower metal layer 10 8a and an upper metal layer 8b formed on the lower metal layer 8a. Although details are not shown, the lower metal layer 8a has a two-layered structure in which a titanium layer and copper layer are stacked in this order from below. Also, the depth of the recess 7 15 is larger than the thickness of the distribution wire 8. In addition, slight spaces 9 are formed between the distribution wire 8 and the inner wall surfaces of the recess 7.

A copper bump electrode 10 is formed on the 20 upper surface of a connecting pad portion of each distribution wire 8. On the upper surface of the protective film 5 including the distribution wires 8, an encapsulating film 11 made of an organic resin such as an epoxy-based resin is formed such that the upper 25 surface of the encapsulating film 11 is leveled with the upper surfaces of the bump electrodes 10. Accordingly, these upper surfaces of the bump

electrodes 10 are exposed. A solder ball 12 is formed on the upper surface of each bump electrode 10.

An example of a method of fabricating this semiconductor device will be explained below. First,  
5 as shown in FIG. 2, a structure is prepared in which connecting pads 2 made of an aluminum-based metal are formed on the upper surface of a silicon substrate 1 in the form of a wafer, an insulating film 3 made of an inorganic insulating material such as silicon oxide or  
10 silicon nitride is formed on the upper surfaces of the silicon substrate 1 and the connecting pads 2 except for central portions of the connecting pads 2, and these central portions of the connecting pads 2 are exposed through holes 4 formed in the insulating  
15 film 3.

A protective film 5 made of an organic resin such as a polyimide resin is formed by a coating method on the entire upper surface of the insulating film 3 including the upper surface portions of the connecting pads 2 exposed through the holes 4. A resist film 21 is then formed on the upper surface of the protective film 5 except for prospective formation regions of recesses 7 (i.e., distribution wires 8). As shown in FIG. 3, the resist film 21 is used as a mask to  
20 half-etch the protective film 5, thereby forming recesses 7 in the upper surface of the protective film 5 except for regions below the resist film 21. Note  
25

that when etched by an etching solution, each recess 7  
is actually inclined in the direction of thickness such  
that the width of the bottom surface of the recess 7 is  
smaller than that of the upper surface. However, each  
5 recess 7 is shown as a vertical recess in the figures  
for the sake of simplicity. In this case, dry etching  
such as plasma etching is applicable as the  
half-etching of the protective film 5. Anisotropic  
etching is particularly preferable because the inclined  
10 surface is made as vertical as possible. The resist  
film 21 is then peeled.

As shown in FIG. 4, a resist film 22 is formed by  
depositing and then patterning, on the upper surface of  
the protective film 5. In this state, holes 23 are  
15 formed in those portions of the resist film 22, which  
correspond to the holes 4 in the insulating film 3.  
Subsequently, as shown in FIG. 5, the resist film 22 is  
used as a mask to selectively etch the protective film  
5, thereby forming holes 6 in those portions of the  
protective film 5, which correspond to the holes 23 in  
20 the resist film 22, i.e., the holes 4 in the insulating  
film 3. After that, the resist film 22 is peeled.

As shown in FIG. 6, a lower metal layer or a base  
layer 8a is formed on the entire upper surface of the  
protective film 5 and the upper surface portions of the  
25 connecting pads 2 exposed through the holes 4 and 6.  
Although details are not shown, the lower metal layer

8a is obtained by forming a copper layer by sputtering on a titanium layer which is also formed by sputtering. The lower metal layer 8a may also have another structure and/or another material. For example, the 5 lower metal layer 8a may also be a single copper layer formed by electroless plating.

Subsequently, a plating resist film 24 is formed by depositing and then patterning, on the upper surface of the lower metal layer 8a. In this state, holes 25 10 are formed in those portions of the plating resist film 24, which correspond to prospective formation regions of distribution wires 8. Also, the lower metal layer 8a formed on the inner wall surfaces of each recess 7 in the protective film 5 is covered with the plating 15 resist film 24. The lower metal layer 8a is then used as a plating current path to perform electroplating of copper, thereby forming an upper metal layer 8b on the upper surface of the lower metal layer 8a in each hole 25 of the plating resist film 24. After that, the 20 plating resist film 24 is peeled.

As shown in FIG. 7, a plating resist film 27 is formed by depositing and then patterning, on the upper surface of the lower metal layer 8a including the upper metal layer 8b. In this state, holes 28 are formed in 25 those portions of the plating resist film 27, which correspond to connecting pad portions of the upper metal layer 8b. Also, around the upper metal layer 8b,

the lower metal layer 8a formed on the inner wall surfaces of each recess 7 in the protective film 5 is covered with the part of the plating resist film 27. The lower metal layer 8a is then used as a plating current path to perform electroplating of copper, thereby forming bump electrodes 10 on the upper surfaces of the connecting pad portions of the upper metal layer 8b in the holes 28 of the plating resist film 27.

The plating resist film 27 is peeled, and then the bump electrodes 10 and upper metal layer 8b are used as masks to etch away unnecessary portions of the lower metal layer 8a. Consequently, as shown in FIG. 8, the lower metal layer 8a remains only below the upper metal layer 8b in the recesses 7, so that a distribution wire 8 is formed by the residual lower metal layer 8a and the upper metal layer 8b formed on the entire upper surface of the lower metal layer 8a. At the same time, a slight space 9 is formed between each distribution wire 8 and the inner wall surfaces of the recess 7. The space is a positional deviation amount when the plating resist film 28 is printed, and is usually a few  $\mu\text{m}$  or less. As will be described later, the lower metal layer 8a is much thinner than the upper metal layer 8b. Therefore, when an etching solution is sprayed against the entire surface for short time periods, only those portions of the lower metal layer

8a, which extend outside the bump electrodes 10 and upper metal layer 8b are removed.

As shown in FIG. 9, an encapsulating film 11 made of an organic resin such as an epoxy resin is formed on the upper surfaces of the protective film 5, the bump electrodes 10 and distribution wires 8, such that the thickness of the encapsulating film 11 is slightly larger than the height of the bump electrodes 10. In this state, the encapsulating film 11 is also formed in the recesses 7 including the spaces 9. Also, the upper surfaces of the bump electrodes 10 are covered with the encapsulating film 11.

As shown in FIG. 10, the encapsulating film 11 and the upper surfaces of the bump electrodes 10 are appropriately polished to expose these upper surfaces of the bump electrodes 10. Subsequently, as shown in FIG. 11, a solder ball 12 is formed on the upper surface of each bump electrode 10. When a dicing step is performed after that, a plurality of semiconductor devices shown in FIG. 1 are obtained.

In the thus obtained semiconductor device, the distribution wire 8 is formed in each recess 7 formed in the upper surface of the protective film 5, and the depth of the recess 7 is made larger than the thickness of the distribution wire 8. Therefore, between the distribution wires 8 including the lower portions of the bump electrodes 10, the protective film 5 has

extended portions higher than the upper surface of each distribution wire 8. The extended portion prevents easy occurrence of a short circuit caused by so-called ion migration.

5 Examples of the dimensions are as follows. The thickness of the lower metal layer 8a is about 0.4 to 0.8  $\mu\text{m}$ . The thickness of the upper metal layer 8b is about 1 to 10  $\mu\text{m}$ . The thickness of the extended portion of the protective film 5 is about 10 to 30  $\mu\text{m}$ .

10 The depth of the recess 7 is about 5 to 15  $\mu\text{m}$  (and larger than the thickness of the distribution wire 8). The thickness of the portion of the protective film 5 in the recess 7 is 1 to 20  $\mu\text{m}$ . The height of the bump electrode 10 is about 80 to 150  $\mu\text{m}$ .

15 The width of the distribution wire 8 is set at a desired value in accordance with the number of terminals, layout, and the like of each semiconductor device. For example, the width of the distribution wire 8 is about 20 to 40  $\mu\text{m}$ , and the diameter of the holes 4 and 6 is larger than the width of the distribution wire 8, and about 30 to 60  $\mu\text{m}$ . The diameter of the connecting pad portion of the distribution wire 8 and the bump electrode 10 formed on the connecting pad portion is, e.g., about 200 to 200  $\mu\text{m}$ . Also, the spacing between the distribution wires 8 and the spacing between the distribution wire 8 and the connecting pad portion of the nearby

distribution wire 8 can be about 20  $\mu\text{m}$  or less.

Another formation method of the protective film 5 will be explained below. As shown in FIG. 12, the upper surface of an insulating film 3 is coated with a first protective film 5A made of an organic resin, and holes 6a are formed in the first protective film 5A by photolithography. It is also possible to form a first protective film 5A having holes 6a by screen printing. On the upper surface of the first protective film 5A, a second protective film 5B made of an organic resin and having holes (i.e., recesses) 7a is formed by screen printing. The same structure as the protective film 5 shown in FIG. 1 is formed by the first and second protective films 5A and 5B.

In the above embodiment as shown in FIG. 1, the depth of the recess 7 is larger than the thickness of the distribution wire 8. However, the present invention is not limited to this embodiment. For example, as in the first modification shown in FIG. 13, the depth of the recess 7 may also be substantially the same as the thickness of the distribution wire 8.

In the above embodiment as shown in FIG. 1, the positions of the bump electrodes 10 are different from those of the connecting pads 2. However, the present invention is not limited to this embodiment. For example, as in the second modification shown in FIG. 14, it is also possible to form, on each

connecting pad 2, a distribution wire 8 having only a connecting pad portion whose planar size is larger than that of the connecting pad 2, and form, on the distribution wire 8, a bump electrode 10 whose cross-sectional a planar size is larger than the planar size of the connecting pad 2. In this structure shown in FIG. 14, the distribution wire 8 is formed as a pedestal having functions of a barrier layer and adhesive layer of the bump electrode 10. Migration can be prevented because the adjacent bump electrode 10 and their pedestals are separated by spaces in recesses 7.

If an upper metal layer 8b and the bump electrode 10 are made of the same material in this modification shown in FIG. 14, it is also possible to form only a lower metal layer 8a as a pedestal of each bump electrode 10 and form bump electrode 10 directly on the lower metal layer 8a as in the third modification shown in FIG. 15. The second or third modification shown in FIG. 14 or 15 may also be combined with the embodiment shown in FIG. 1. That is, as shown in FIG. 1, distribution wires 8 are extended onto some connecting pads 2, and bump electrodes 10 are formed on the extended portions of the pads 2. After that, as shown in FIG. 14 or 15, distribution wires (equivalent to connecting pad portions) 8 are formed only on remaining connecting pads 2, and bump electrodes 10 are formed on these distribution wires. In the first embodiment

described above, the distribution wires 8 are covered only with the encapsulating film 11. Therefore, migration may occur if water penetrates into the encapsulating film 11. To prevent this, a more  
5 reliable structure must be obtained. Also, if the bump electrodes 10 protrude from the upper surface of the encapsulating film 11, they can deform more easily when the semiconductor device is connected to a circuit board. This makes it possible to more effectively  
10 reduce the stress generated by the difference between the thermal expansion coefficients of the silicon substrate 1 and the circuit board (not shown). This embodiment will be described below.

(Second Embodiment)

15 FIG. 16 is a sectional view of a semiconductor device as the second embodiment of the present invention. This semiconductor device includes a silicon substrate 1. An integrated circuit or circuits (not shown) are formed in a central portion of the upper surface of the silicon substrate 1. A plurality of connecting pads 2 made of an aluminum-based metal are formed in a peripheral portion of the upper surface of the substrate and electrically connected to the integrated circuit. An insulating film 3 made of an  
20 inorganic insulating material such as silicon oxide or silicon nitride is formed on the upper surfaces of the silicon substrate 1 and the connecting pads 2, except  
25

for central portions of the connecting pads 2. The central portions of the connecting pads 2 are exposed through holes 4 formed in the insulating film 3.

A lower protective film 5 made of an organic resin such as polyimide is formed on the upper surface of the insulating film 3. Holes 6 are formed in those portions of the lower protective film 5, which correspond to the holes 4 in the insulating film 3. Recesses 7 are formed in distribution wire formation regions of the upper surface of the lower protective film 5. The recesses 7 communicate with the holes 6. A distribution wire 8 is formed from the upper surface of each connecting pad 2 exposed through the holes 4 and 6 into the recess 7 of the lower protective film 5. The distribution wire 8 is made up of a lower metal layer 8a and an upper metal layer 8b formed on the lower metal layer 8a. Although details are not shown, the lower metal layer 8a has a two-layered structure in which a titanium layer and copper layer are stacked in this order from below. The upper metal layer 8b is made of a copper layer alone.

At the edge of the silicon substrate 1, the upper metal layer 8b is not stacked on the lower metal layer 8a. That is, on the upper surface of the lower protective film 5, the lower metal layer 8a is formed as a connecting line 8a' which is a single layer and runs to the edge of the silicon substrate 1. A lower

bump electrode 10a and upper bump electrode 10b both made of copper are formed on the upper surface of a connecting pad portion of each distribution wire 8. That is, in this embodiment, a bump electrode 10 has a  
5 two-layered structure made up of the lower bump electrode 10a and upper bump electrode 10b. On the upper surface of the lower protective film 5 including, except for their connecting pad portions, the lower metal layer 8a and upper metal layer 8b formed on the  
10 upper surface of the lower protective film 5, an upper protective film 13 made of an organic resin such as polyimide and an encapsulating film 11 made of an organic resin such as an epoxy-based resin are formed. In this state, the upper surface of the encapsulating  
15 film 11 is leveled with the upper surfaces of the lower bump electrodes 10a. Accordingly, the upper bump electrodes 10b entirely protrude from the encapsulating film 11.

An example of a method of fabricating this  
20 semiconductor device will be explained below. First, as shown in FIG. 17, a structure is prepared in which connecting pads 2 made of an aluminum-based metal are formed on the upper surface of a silicon substrate 1 in the form of a wafer, an insulating film 3 made of an inorganic insulating material such as silicon oxide or  
25 silicon nitride is formed on the upper surfaces of the silicon substrate 1 and the connecting pads 2 except

for central portions of the connecting pads 2. The central portions of the connecting pads 2 are exposed through holes 4 formed in the insulating film 3. In FIG. 17, regions denoted by reference numeral 31 correspond to dicing streets.

As shown in FIG. 18, a lower protective film 5 made of an organic resin such as polyimide is formed by spin coating or the like on the entire upper surface of the insulating film 3 including the upper surfaces of the connecting pads 2 exposed through the holes 4, such that the upper surface of the lower protective film 5 is substantially flat. A resist film 32 is then formed on the upper surface of the lower protective film 5 except for prospective formation regions of recesses 7 (i.e., distribution wires 8). As shown in FIG. 19, the resist film 32 is used as a mask to half-etch the lower protective film 5, thereby forming recesses 7 in the upper surface of the lower protective film 5 except for regions below the resist film 32. The resist film 32 is then peeled.

As shown in FIG. 20, a resist film 33 is formed by patterning on the upper surface of the lower protective film 5. In this state, holes 34 are formed in those portions of the resist film 33, which correspond to the holes 4 in the insulating film 3. Subsequently, as shown in FIG. 21, the resist film 33 is used as a mask to selectively etch the lower protective film 5,

thereby forming holes 6 in those portions of the lower protective film 5, which correspond to the holes 34 in the resist film 33, i.e., the holes 4 in the insulating film 3. After that, the resist film 33 is peeled.

5 As shown in FIG. 22, a lower metal layer 8a is formed on the entire upper surface of the lower protective film 5 and the upper surfaces of the connecting pads 2, exposed through the holes 4 and 6. Although details are not shown, the lower metal layer 10 8a is obtained by forming a copper layer by sputtering on a titanium layer which is also formed by sputtering. The lower metal layer 8a may also be a single copper layer formed by electroless plating.

Subsequently, a resist film 35 is formed by 15 patterning on the upper surface of the lower metal layer 8a. In this state, holes 36 are formed in those portions of the resist film 35, which correspond to prospective formation regions of distribution wires 8. That is, the edge of each hole 36 continues to the 20 inner wall surface of the lower metal layer 8a formed in the recess 7. The lower metal layer 8a is then used as a plating current path to perform electroplating of copper, thereby forming an upper metal layer 8b on the upper surface of the lower metal layer 8a in the recess 25 7. In this state, the upper surface of the upper metal layer 8b is substantially leveled with the upper surface of the portion of the lower metal layer 8a

under the resist film 35. After that, the resist film 35 is peeled.

As shown in FIG. 23, a resist film 37 is formed by depositing and then patterning, on the portions of the upper surface of the lower metal layer 8a and the upper metal layer 8b. FIG. 24 is a plan view of the state shown in FIG. 23 (FIG. 24 shows a region wider than that shown in FIG. 23). As shown in FIG. 24, the resist film 37 has a shape including portions 37a corresponding to the upper metal layer 8b, portions 37b corresponding to the dicing streets 31 indicated by the alternate long and short dashed lines, and portions 37c corresponding to the upper metal layer 8b between the connecting pads 2 and dicing streets 31.

The resist film 37 is then used as a mask to etch away unnecessary portions of the lower metal layer 8a. When the resist film 37 is peeled after that, a structure as shown in FIGS. 25 and 26 is obtained. That is, a distribution wire 8 is formed in each recess 7. The distribution wire 8 has the upper metal layer 8b whose upper surface is exposed and lower and side surfaces are covered with the lower metal layer 8a. Also, lattice-like auxiliary wires 38 made of the lower metal layer 8a alone are formed in regions corresponding to the dicing streets 31 indicated by the alternate long and short dashed lines. In addition, connecting lines 8a' made of the lower metal layer 8a

alone are formed between the auxiliary wires 38 and distribution wires 8.

As shown in FIG. 27, an upper protective film 13 made of an organic resin such as polyimide, i.e., the same material as the lower protective film 5, is formed by spin coating or the like, on the entire upper surface of the lower protective film 5, the distribution wires 8, connecting lines 8a', and auxiliary wires 38, such that the upper surface of the upper protective film 13 is substantially flat. A resist pattern 39 is then formed by depositing and then patterning, on the upper surface of the upper protective film 13. In this state, holes 40 are formed in those portions of the resist film 39, which correspond to connecting pad portions of the distribution wires 8.

As shown in FIG. 28, the resist film 39 is used as a mask to selectively etch the upper protective film 13, thereby forming holes 41 in those portions of the upper protective film 13, which correspond to the holes 40 in the resist film 39, i.e., the connecting pad portions of the distribution wires 8. Subsequently, as shown in FIG. 29, the auxiliary wires 38 are used as masks to perform electroplating of copper, thereby forming lower bump electrodes 10a on the upper surfaces of the connecting pad portions of the distribution wires 8 in the holes 40 and 41 of the resist film 39 and upper protective film 13, respectively. After

that, the resist film 39 is peeled.

As shown in FIG. 30, an encapsulating film 11 made of an organic resin such as an epoxy resin is formed on the upper surface of the upper protective film 13, 5 the lower bump electrodes 10a, distribution wires 8, connecting lines 8a', and auxiliary wires 38, such that the thickness of the encapsulating film 11 is slightly larger than the height of the lower bump electrodes 10a. In this state, therefore, the upper surfaces of 10 the lower bump electrodes 10a are covered with the encapsulating film 11. Subsequently, as shown in FIG. 31, the encapsulating film 11 and the upper surfaces of the lower bump electrodes 10a are appropriately polished to expose these upper surfaces 15 of the lower bump electrodes 10a, and planarize the upper surface of the encapsulating film 11 including the upper surfaces of the lower bump electrodes 10a..

As shown in FIG. 32, a resist film 42 is formed by depositing and then patterning, on the upper surface of 20 the encapsulating film 11. In this state, holes 43 are formed in those portions of the resist film 42, which correspond to the upper surfaces of the lower bump electrodes 10a. The auxiliary wires 38 are then used 25 as plating current paths to perform electroplating of copper, thereby forming upper bump electrodes 10b on the upper surfaces of the lower bump electrodes 10a in the holes 43 of the resist film 42. In this way, bump

electrodes 10 having a two-layered structure are formed. Subsequently, as shown in FIG. 33, the resist film 42 and the upper surfaces of the upper bump electrodes 10b are appropriately polished to planarize the upper surface of the resist film 42 including the upper surfaces of the upper bump electrodes 10b.

Next, the resist film 42 is peeled, as shown in FIG. 34, so that the upper bump electrodes 10b entirely protrude from the encapsulating film 11. A plurality of semiconductor devices shown in FIG. 16 are obtained by dicing the wafer-like silicon substrate 1 and members thereon in the regions 31 corresponding to dicing streets. Since the silicon substrate 1 in the form of a wafer is diced in the regions 31 corresponding to dicing streets, the auxiliary wires 38 formed in the regions 31 corresponding to dicing streets are removed. Accordingly, the distribution wires 8 are not short-circuited.

In the semiconductor device thus obtained, the distribution wires 8, except for their connecting pad portions, formed in the recesses 7 on the upper surface of the lower protective film 5 are covered with the upper protective film 13 made of the same material as the lower protective film 5. Therefore, even if water in the use environment penetrates into the encapsulating film 11, further penetration of the water is inhibited by the upper surface of the upper

protective film 13. This prevents easy occurrence of a short circuit caused by so-called ion migration between the distribution wires 8 and between the distribution wires 8 and bump electrodes 10.

5 Referring to FIG. 16, the lower bump electrode 10a and upper bump electrode 10b are separated by the solid line between them, for the sake of convenience. In practice, however, there is no such interface separating the two bump electrodes 10a and 10b that  
10 is, both electrodes 10a, 10b are integral, because both of them are formed by electroplating of copper.  
Accordingly, the upper portion of each bump electrode 10 formed on the upper surface of the connecting pad portion of the distribution wire 8 actually protrudes  
15 from the encapsulating film 11. As a consequence, when solder balls (not shown) are formed on the bump electrodes 10 and connected to connecting terminals of a circuit board, the bump electrodes 10 can deform more easily. This makes it possible to more effectively  
20 reduce the stress generated by the difference between the thermal expansion coefficients of the silicon substrate 1 and the circuit board (not shown).

(Other Examples of Fabrication Method of Second Embodiment)

25 In the above fabrication method, unnecessary portions of the lower metal layer 8a are removed as shown in FIG. 25, the upper protective film 13 is

formed as shown in FIG. 28, and the lower bump electrodes 10a are formed as shown in FIG. 29. However, the present invention is not limited to this method. For example, after a lower metal layer 8a is formed on the entire surface of a lower protective film 5 and distribution wires 8 are formed in recesses 7 of the lower protective film 5 as shown in FIG. 22, a resist film 51 is formed by depositing and then patterning on the upper surface of the distribution wires 8 without patterning the lower metal layer 8a as shown in FIG. 35. In this state, holes 52 are formed in those portions of the resist film 51, which correspond to connecting pad portions of the distribution wires 8. The lower metal layer 8a is then used as a plating current path to perform electroplating of copper, thereby forming lower bump electrodes 10a on the upper surfaces of the connecting pad portions of the distribution wires 8 in the holes 52 of the resist film 51. After that, the resist film 51 is peeled.

As shown in FIG. 36, a resist film 53 is formed by depositing and then patterning of the resist, on the lower metal layer 8a including the distribution wires 8. The resist film 53 has the same pattern as the resist film 27 shown in FIGS. 23 and 24 except that the resist film 53 is not formed in regions corresponding to the lower bump electrodes 10a. The resist film 53

and the lower bump electrodes 10a are then used as a mask to etch away unnecessary portions of the lower metal layer 8a. After that, the resist film 53 is peeled. Subsequently, as shown in FIG. 37, the upper 5 protective film 13 is formed by spin coating or the like on the upper surface of the lower protective film 5 including the distribution wires 8 and the like, except for the regions where the lower bump electrodes 10a are formed, such that the upper surface of the 10 upper protective film 13 is substantially flat. A plurality of semiconductor devices shown in FIG. 16 are obtained through the steps shown in FIGS. 30 to 34 after that.

Also, in the distribution wire 8 formation step 15 shown in FIG. 22 of the second embodiment, if the upper surface of the upper metal layer 8b formed by electroplating of copper is substantially leveled with the upper surface of the lower protective film 5, a semiconductor device shown in FIG. 38 as the first 20 modification of the second embodiment is obtained. In this structure, the upper surface of the lower metal layer 8a around the upper metal layer 8b may also be substantially leveled with the upper surface of the distribution wire 8.

25 The connecting lines 8a' used as current paths when the upper bump electrodes 10b are formed have a single-layered structure made of the lower metal layer

8a alone. However, as shown in FIG. 39 as the second modification of the second embodiment, connecting lines 8a' may also have a two-layered structure, similar to that of the distribution wires 8, in which an upper metal layer 8b is formed on a lower metal layer 8a. In this case, in the step of forming recesses 7 shown in FIG. 18, the pattern of a resist film 32 formed on the upper surface of a lower protective film 5 is also removed from regions 31 corresponding to dicing streets and their nearby regions, and the obtained resist film 32 is used as a mask to half-etch the lower protective film 5. Consequently, in the state shown in FIG. 19, recesses 7 are formed in the upper surface of the lower protective film 5 in the regions 31 corresponding to dicing streets and their nearby regions. After that, a lower metal layer 8a is formed, and then an upper metal layer 8b is formed by electroplating, thereby obtaining the structure shown in FIG. 39. When this fabrication method is used, therefore, the connecting lines 8' having a two-layered structure including the lower metal layer 8a and upper metal layer 8b are formed in the recesses 7 near the end faces of a silicon substrate 1. In this semiconductor device, auxiliary wires formed in the regions 31 corresponding to dicing streets also have the two-layered structure.

FIG. 40 is a sectional view of a semiconductor device as the third modification of the second

embodiment. This semiconductor device largely differs from that shown in FIG. 16 in that no recesses 7 are formed in the upper surface of a lower protective film 5, so the upper surface of the lower protective film 5 is substantially flat. Even in a structure like this, distribution wires 8 except for their connecting pad portions are covered with an upper protective layer 13. This prevents easy occurrence of a short circuit caused by so-called ion migration between the distribution wires 8 and between the distribution wires 8 and lower bump electrodes 10a.

FIG. 41 is a sectional view of a semiconductor device as the fourth modification of the second embodiment. This semiconductor device largely differs from that shown in FIG. 16 in that the height of each bump electrode 10A is the total height of the upper and lower bump electrodes, and the upper surface of an encapsulating film 11A is leveled with the upper surfaces of the bump electrodes 10A.

In the semiconductor device shown in FIG. 16, the thickness of the encapsulating film 11 is decreased by the height of the upper bump electrode 10b, so the upper bump electrode 10b protrudes from the encapsulating film 11, when compared to the semiconductor device shown in FIG. 41. This makes it possible to further reduce the stress caused by the difference between the thermal expansion coefficients

of the silicon substrate 1 and a circuit board. On the other hand, when the thickness of the encapsulating film 11 is decreased by the height of the upper bump electrode 10b, water in the use environment penetrates  
5 into the encapsulating film 11 more easily than in the semiconductor device shown in FIG. 41. However, further penetration can be inhibited by the upper surface of the upper protective film 13. This prevents easy occurrence of a short circuit caused by so-called  
10 ion migration.

When the thickness of the encapsulating film 11 is decreased by the height of the upper bump electrode 10b, a warp of the silicon substrate 1 in the form of a wafer can be made smaller than that in the  
15 semiconductor device shown in FIG. 41. For example, assume that in the semiconductor device shown in FIG. 16, the thickness of the lower protective film 5 is about 10  $\mu\text{m}$ , the thickness of the upper protective film 13 is about 4  $\mu\text{m}$ , the depth of the recess 7 is about 6  $\mu\text{m}$ , and the height of the bump electrode 10 is about 100  $\mu\text{m}$ . In this case, the thickness of the encapsulating film 11 is determined by the height of the upper bump electrode 10b.  
20

When the silicon substrate 1 in the form of a  
25 wafer was a 200- $\mu\text{m}$  type substrate and the height of the upper bump electrode 10b was 0  $\mu\text{m}$  (i.e., the same as in the semiconductor device shown in FIG. 41), a warp of

the wafer-like silicon substrate 1 was about 1 mm. In contrast, when the heights of the upper bump electrodes 10b were 22.5 and 45  $\mu\text{m}$ , warps of the wafer-like silicon substrates 1 were about 0.7 and 0.5 mm,  
5 respectively. Since a warp of the silicon substrate 1 in the form of a wafer can be reduced as described above, transfer to the subsequent steps and the processing accuracy in these subsequent steps are not easily affected.

10 The first and second embodiments described above have the structure in which the recess 7 is formed in the protective film 5, and the distribution wire 8 is formed in the recess 7 (except the device shown in FIG. 40). In the present invention, however, it is  
15 also possible to form the distribution wires 8 on the upper surface of the protective film 5, and form the recesses 7 in the protective film 5 between the distribution wires 8. This embodiment will be explained below.

20 (Third Embodiment)

FIG. 42 is a sectional view of a semiconductor device as the third embodiment of the present invention. This semiconductor device includes a silicon substrate 1. An integrated circuit (not shown)  
25 is formed in a central portion of the upper surface of the silicon substrate 1. A plurality of connecting pads 2 made of an aluminum-based metal are formed in a

peripheral portion of the upper surface of the silicon substrate 1 and electrically connected to the integrated circuit.

An insulating film 3 made of silicon oxide is formed on the upper surface of the silicon substrate 1 and the connecting pads 2 except for central portions of the connecting pads 2. These central portions of the connecting pads 2 are exposed through holes 4 formed in the insulating film 3. A protective film 5 made of polyimide is formed on the upper surface of the insulating film 3. Holes 6 are formed in those portions of the protective film 5, which correspond to the holes 4 in the insulating film 3. Recesses 107 are formed in the upper surface of the protective film 5 except for distribution wire formation regions.

A distribution wire 8 is formed to extend from the upper surface of each connecting pad 2 exposed through the holes 4 and 6 to the upper surface of the protective film 5. The distribution wire 8 has a two-layered structure made up of a lower metal layer 8a and an upper metal layer 8b formed on the lower metal layer 8a. Although details are not shown, the lower metal layer 8a has a two-layered structure in which a titanium layer and copper layer are stacked in this order from below. The upper metal layer 8b is made of a copper layer alone.

A copper bump electrode 10 is formed on the upper

surface of a connecting pad portion of each distribution wire 8. On the upper surface of the protective film 5 and the distribution wires 8, an encapsulating film 11 made of an epoxy-based resin is formed such that the upper surface of the encapsulating film 11 is leveled with the upper surfaces of the bump electrodes 10.

An example of a method of fabricating this semiconductor device will be explained below. First, as shown in FIG. 43, a structure is prepared in which connecting pads 2 made of an aluminum-based metal, an insulating film 3, and a protective film 5 are formed on a silicon substrate 1 in the form of a wafer, and central portions of the connecting pads 2 are exposed through holes 4 and 6 respectively formed in the insulating film 3 and protective film 5, respectively. In FIG. 43, regions denoted by reference numeral 31 correspond to dicing streets.

As shown in FIG. 44, a lower metal layer 8a is formed on the entire upper surface of the protective film 5 and the upper surfaces of the connecting pads 2 exposed through the holes 4 and 6. Although details are not shown, the lower metal layer 8a is obtained by forming a copper layer by sputtering on a titanium layer which is also formed by sputtering. The lower metal layer 8a may also be a single copper layer formed by electroless plating.

Subsequently, a resist film 62 is formed by  
depositing and then patterning of the resist, on the  
upper surface of the lower metal layer 8a. In this  
state, holes 63 are formed in those portions of the  
5 resist film 62, which correspond to prospective  
formation regions of an upper metal layer 8b. The  
lower metal layer 8a is then used as a plating current  
path to perform electroplating of copper, thereby  
forming upper metal layers 8b on those portions of the  
10 upper surface of the lower metal layer 8a, which  
correspond to the holes 63 in the resist film 62.  
After that, the resist film 62 is peeled.

As shown in FIG. 45, a patterned resist film 64 is  
formed on the upper surface of the lower metal layer 8a  
15 and the upper metal layer 8b. In this state, holes 65  
are formed in those portions of the resist film 64,  
which correspond to prospective formation regions  
of bump electrodes 10. The lower metal layer 8a is  
then used as a plating current path to perform  
20 electroplating of copper, thereby forming the bump  
electrodes 10 on the upper surfaces of those connecting  
pad portions of the upper metal layer 8b, which  
correspond to the holes 65 in the resist film 64.

The resist film 64 is peeled, and the bump  
25 electrodes 10 and upper metal layer 8b are used as  
masks to etch away unnecessary portions of the lower  
metal layer 8a. Consequently, as shown in FIG. 46, the

lower metal layer 8a remains only below the upper metal layer 8b to form a distribution wire 8.

As shown in FIG. 47, the bump electrodes 10 and distribution wires 8 are used as masks to half-etch the protective film 5, thereby forming recesses 107 in the upper surface of the protective film 5 except for regions below the distribution wires 8. Although the depth of each recess 107 depends upon the thickness of the protective film 5, this depth is, e.g., 1 to 5  $\mu\text{m}$ .  
5 The width of the distribution wire 8 and the minimum spacing between the distribution wires 8 are, e.g., 10 to 20  $\mu\text{m}$ . Note that when etched by an etching solution, each recess 107 is inclined in the direction of thickness such that the width of the bottom surface of the recess 107 is smaller than that of the upper surface. However, each recess 7 is shown as a vertical recess in the figure for the sake of simplicity. In  
10 this case, dry etching such as plasma etching is applicable as the half-etching of the protective film.  
15 5. Anisotropic etching is particularly preferable because the inclined surface is made as vertical as possible.  
20

As shown in FIG. 48, an encapsulating film 11 made of an organic resin such as an epoxy resin is formed on the entire upper surface of the protective film 5 the bump electrodes 10, the distribution wires 8, and the recesses 107, such that the thickness of the  
25

encapsulating film 11 is slightly larger than the height of the bump electrodes 10. In this state, therefore, the upper surfaces of the bump electrodes 10 are covered with the encapsulating film 11.

5 As shown in FIG. 49, the encapsulating film 11 and the upper surfaces of the bump electrodes 10 are appropriately polished to expose these upper surfaces of the bump electrodes 10, and planarize the upper surface of the encapsulating film 11 including the upper surfaces of the bump electrodes 10. A plurality of semiconductor devices shown in FIG. 42 are obtained by dicing the wafer-like silicon substrate 1 in regions 10 31 corresponding to dicing streets.

In the semiconductor device thus obtained, the 15 recesses 107 formed in the upper surface of the protective film 5 are present between the distribution wires 8 formed on the upper surface of the protective film 5. Therefore, the length of the interface of the protective film 5 and encapsulating film 11 between the 20 distribution wires 8, i.e., the length of the copper ion precipitation path is twice as large as the depth of the recesses 7. This prevents easy occurrence of a short circuit caused by so-called ion migration between the distribution wires 8 and between the distribution 25 wires 8 and bump electrodes 10 accordingly.

FIG. 50 is a sectional view of a semiconductor device as a modification of the third embodiment of the

present invention. This semiconductor device largely differs from that shown in FIG. 42 in that an upper protective layer 15 made of an organic resin such as polyimide is formed between a protective film 5 including distribution wires 8 and an encapsulating film 11. In this semiconductor device, no recess is formed in the upper surface of the protective film 5 near the end faces of a silicon substrate 1.

On the upper surface of the protective film 5 near connecting pads 2, connecting lines 8' formed by extending the distribution wires 8 run to the end faces of the silicon substrate 1. Each connecting line 8' has a two-layered structure including a lower metal layer 8a and upper metal layer 8b, similar to that of the distribution wire 8.

An example of a method of fabricating this semiconductor device will be explained below. First, as shown in FIG. 51, holes 73 are formed in those portions of a resist film 72, which correspond to prospective formation regions of distribution wires 8, prospective formation regions of connecting lines 8' and prospective formation regions of auxiliary wires 38' in regions 31 corresponding to dicing streets. A lower metal layer 8a is then used as a plating current path to perform electroplating of copper, thereby forming an upper metal layer 8b on the upper surface of the lower metal layer 8a in the holes 73 of the resist

film 72. In this state, the upper metal layer 8b is formed in a lattice manner in the regions corresponding to dicing streets.

The resist film 72 is peeled, and the upper metal layer 8b is used as a mask to etch away unnecessary portions of the lower metal layer 8a. Consequently, as shown in FIG. 52, the lower metal layer 8a remains only below the upper metal layer 8b, thereby forming distribution wires 8 having a two-layered structure in which the upper metal layer 8b is formed on the lower metal layer 8a, forming auxiliary wires 38' in a lattice manner in the regions 31 corresponding to dicing streets, and forming connecting lines 8' for connecting the distribution wires 8 and auxiliary wires 38'. Subsequently, as shown in FIG. 53, the distribution wires 8, connecting lines 8', and auxiliary wires 38' are used as masks to half-etch the protective film 5, thereby forming recesses 107 in the upper surface of the protective film 5 except for regions below the distribution wires 8, connecting lines 8', and auxiliary wires 38'.

As shown in FIG. 54, on the entire upper surface of the protective film 5 including the distribution wires 8, connecting lines 8', auxiliary wires 38', and recesses 7, an upper protective film 15 made of an organic resin such as polyimide is formed by spin coating or the like such that the upper surface of the

upper protective film 15 is substantially flat. A resist pattern 81 is then formed by depositing and then patterning of the resist, on the upper surface of the upper protective film 15. In this state, holes 82 are  
5 formed in those portions of the resist film 81, which correspond to connecting pad portions of the distribution wires 8.

As shown in FIG. 55, the resist film 81 is used as a mask to etch the upper protective film 15, thereby  
10 forming holes 83 in those portions of the upper protective film 15, which correspond to the holes 82 in the resist film 81, i.e., the connecting pad portions of the distribution wires 8. Subsequently, as shown in FIG. 56, the distribution wires 8, connecting lines 8',  
15 and auxiliary wires 38' are used as masks to perform electroplating of copper, thereby forming bump electrodes 10 on the upper surfaces of the connecting pad portions of the distribution wires 8 in the holes 82 and 83 of the resist film 81 and upper protective film 15, respectively. After that, the resist film 81  
20 is peeled.

Following the same procedures as in the third embodiment described above, an encapsulating film 11 is formed, the encapsulating film 11 and the upper  
25 surfaces of the bump electrodes 10 are appropriately polished, and a silicon substrate 1 in the form of a wafer is diced in the regions 31 corresponding to

dicing streets, thereby obtaining a plurality of semiconductor devices shown in FIG. 50. Since the silicon substrate 1 in the form of a wafer is diced in the regions 31 corresponding to dicing streets, the auxiliary wires 38 formed in the regions 31 corresponding to dicing streets are removed. Accordingly, the distribution wires 8 are not short-circuited.

In the semiconductor device thus obtained, the distribution wires 8 except for their connecting pad portions are covered with the upper protective film 15 made of the same material as the lower protective film 5. Therefore, even if water in the use environment penetrates into the encapsulating film 11, further penetration of the water is inhibited by the upper surface of the upper protective film 15. This prevents easy occurrence of a short circuit caused by so-called ion migration between the distribution wires 8 and between the distribution wires 8 and bump electrodes 10. It is of course possible, by the recesses 107, to prevent easy occurrence of a short circuit by so-called ion migration between the distribution wires 8 and between the distribution wires 8 and bump electrodes 10. In this case, the width of the recess 107 can also be made smaller than the spacing between the distribution wires 8.

Additional advantages and modifications will

readily occur to those skilled in the art. Therefore,  
the invention in its broader aspects is not limited to  
the specific details and representative embodiments  
shown and described herein. Accordingly, various  
5 modifications may be made without departing from the  
spirit or scope of the general inventive concept as  
defined by the appended claims and their equivalents.